Metamorphic processes shaping the Earth's surface

The Metamorphic Earth

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Metamorphic processes - one of the key geological parameters responsible for shaping our planet - can be classified into varying types, each of them delimited by its own set of boundary conditions

Different metamorphic processes occur under various conditions and geological environments, in the Earth's crust or deeper within the planet's mantle. They also involve a very wide range of temperatures and pressures.

Varying processes, differing rocks

The definition of "metamorphism" embraces numerous mineral, structural, and textural transformations of solid rock. The processes occur under high temperature and/or pressure, although there are certain exceptions. Researchers distinguish four main categories of metamorphism: dynamic, contact (thermal), shock (impact), and regional.

Dynamic metamorphism involves rock transformations caused by motion during tectonic processes, without the participation of magma. The main parameter is the relative pressures of the advancing rock massifs; they are crushed and granulated to the point of destruction of the mineral structure and vitrification (being turned into glass), followed by recrystallization. The entire process occurs without any external elements, with the exception of water. The processes are local, taking place in tectonic fault zones.

In another type of process, rocks that are in the contact zone with a magma body are subject to reconstruction and recrystallization of their component minerals, usually without any changes to the chemical composition - although the effect of the magma body and fluids associated with it can also be observed. These types of changes are known as local contact metamorphism.

An impact wave caused by a falling extraterrestrial body (meteorite) or an explosion can result in a change to the structure and texture of rocks and minerals; this is known as impact metamorphism, caused by the attendant shock wave. Such a wave may last from a millionth of a second to a minute after the event and causes a rapid increase of temperature and pressure, initiating a process characterized by ongoing changes to the chemical, physical, mineral, textural, and structural properties of rock.

The broadest impact is generated by processes known as regional metamorphism, which can cover many thousands of square kilometers. This is driven by temperatures and hydrostatic pressure, as well as the relative pressure of the advancing rock massifs. This type of metamorphism is further subdivided into high- and low-temperature, and high- and low-pressure. Geologists commonly distinguish individual "facies" (bodies of rock sharing particular characteristics), which are named after minerals characteristic of the given type of rock. They include zeolite, greenschist, blueschist, epidote, granulite and eclogite facies, and metamorphic grades of chlorite, biotite, garnet, andalusite, and other zones.

Due to the presence of many characteristic minerals formed under specific temperature and pressure conditions, microscopic observations of metamorphic rocks enable us to ascertain what metamorphic processes the given rock was subjected to, and which type of metamorphic facies we are observing. The temperature and pressure ranges at which particular minerals or types

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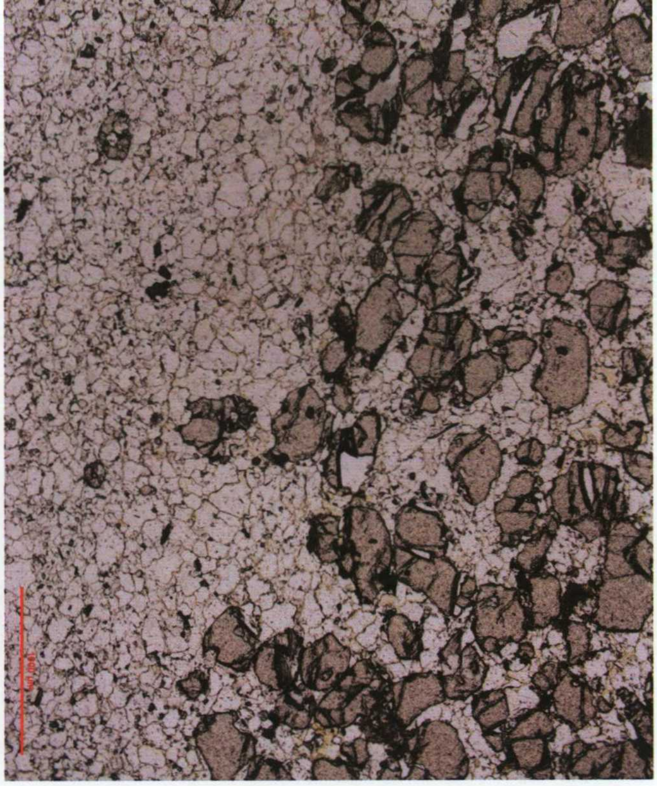
Outcrop of eclogite lens near the village of Bielice in the Bialskie Mountains. Size: 8.5 x 4.5 m

Microscopic photograph of eclogite



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Microscopic photograph of light granulite and garnetite

of minerals occur have been precisely pinned down. Algorithms have been developed for calculating what temperatures and pressures crystallization processes must have occurred under, based on the content of particular elements present in minerals co-occurring in a given rock. Petrogenetic grids have also been devised - diagrams of temperature and pressure ranges under which particular minerals occur, and the ranges under which the conditions of temperatures and pressures correspond to individual metamorphic facies.

Between temperature, pressure and...

Metamorphic processes start within a range of temperatures higher than values characteristic of diagenesis processes that merge sediment on a lake or seabed into solid rock (around 50°C). Warmer conditions favor the formation of oil (50-150°C) and gas (150-230°C) windows - environments under which crude oil and natural gas are formed from certain types of sediment rock rich in organic substances. Such conditions are present at depths of around 0.5-1km beneath the Earth's surface, rich in minerals such as zeolite, prehnite, and pumpellyite. Changes also occur when temperatures exceed 1000°C and pressures 20 kbar (in the oceanic crust with a thickness of 5-7 km, the continental crust with a thickness of up to 30 km, and within mountains with a thickness of up to 70 km).

As well as temperature and pressure, metamorphic processes are also crucially influenced by the water vapor pressure within the rock, reducing the temperature at which rock melts. Dry rocks with a low vapor pressure and with a low content of water-containing minerals melt at significantly higher temperatures than rocks with a high vapor pressure. Because metamorphic processes only occur in the solid phase, conditions suitable for rocks to melt set the upper limit of metamorphic processes.

Additionally, it is common for conditions to arise under which one plate of the Earth's crust slides under another. This leads to subduction, when the lower plate (usually a heavy plate of oceanic crust) is pushed deeply into the upper mantle (down to depths of 200 or even 300 km). Rocks forming such fragments of the crust are subjected to significantly higher pressures (60-100 kbar). Such conditions lead to changes in the density of atoms and the inter-atom distance within mineral structures (known as phase transitions), in both the crust and the upper mantle. This results in altered crystalline structures, volumes, and crystallographic forms of minerals or whole mineral asemblages, without altering the composition of the rock. Researchers believe that this is what is responsible for the rapid acceleration of longitudinal seismic waves observed at such depths, interpreted by geologists and geophysicists as the Mohorovičić (or "Moho") discontinuity. This acceleration may correspond to chemical changes in the crust (mafic) and upper mantle (ultramafic), or phase transformation of gabbro into eclogite.

Beyond our own planet, such as on the Moon, it is impact metamorphism, resulting from meteorite strikes, that is the most common type. Such impacts lead to massive surges in temperature and pressure, resulting in chemical, physical, and mineral changes. This in turn leads to even greater alterations in the packing and distance between atoms and in the density of minerals, and to the melting of rock (at pressures exceeding as much as 1000 kbar and temperatures of several thousand degrees or higher). ■

Further reading:

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